SUCRe: Leveraging Scene Structure for Underwater Color Restoration

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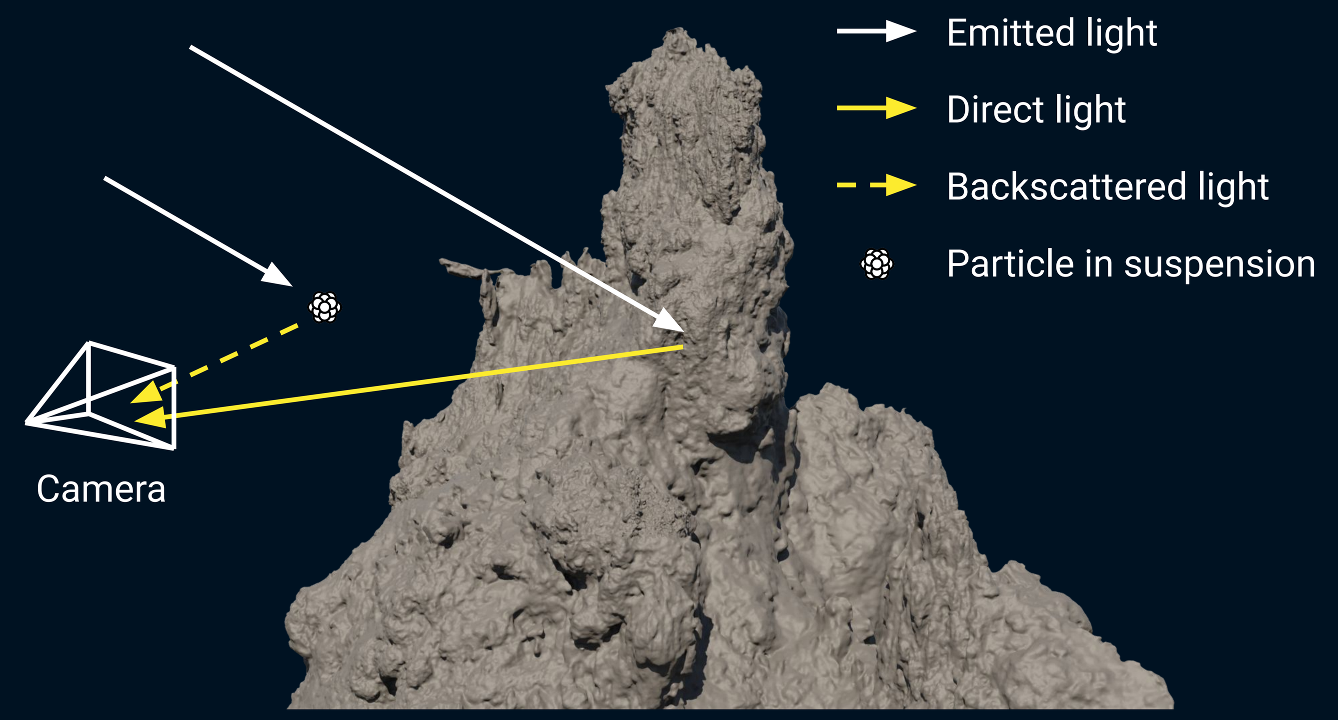
Context – Underwater images



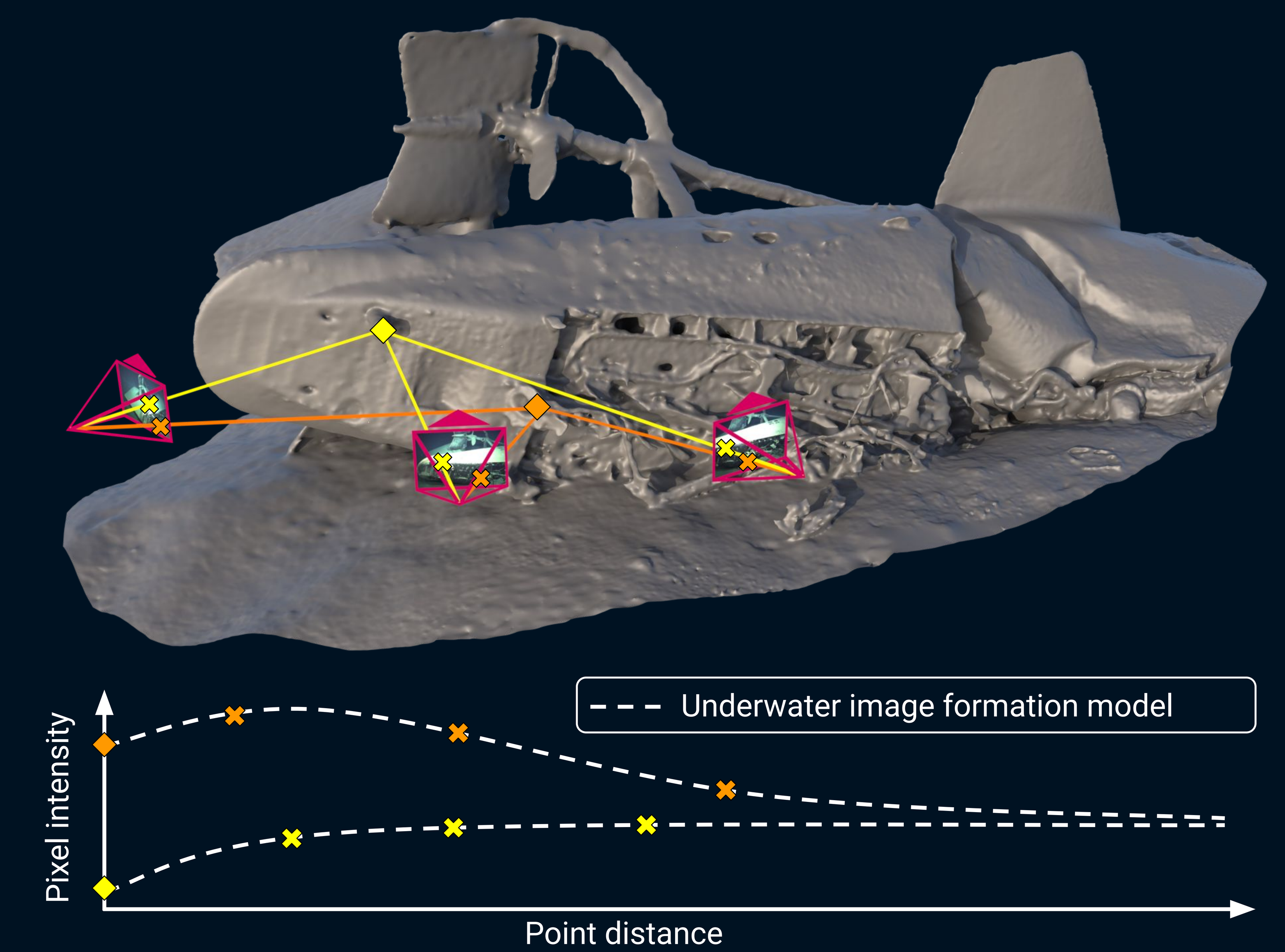
Light is strongly attenuated by the water medium:
- **absorption** along the water column
- **backscatter** due to collision with particles

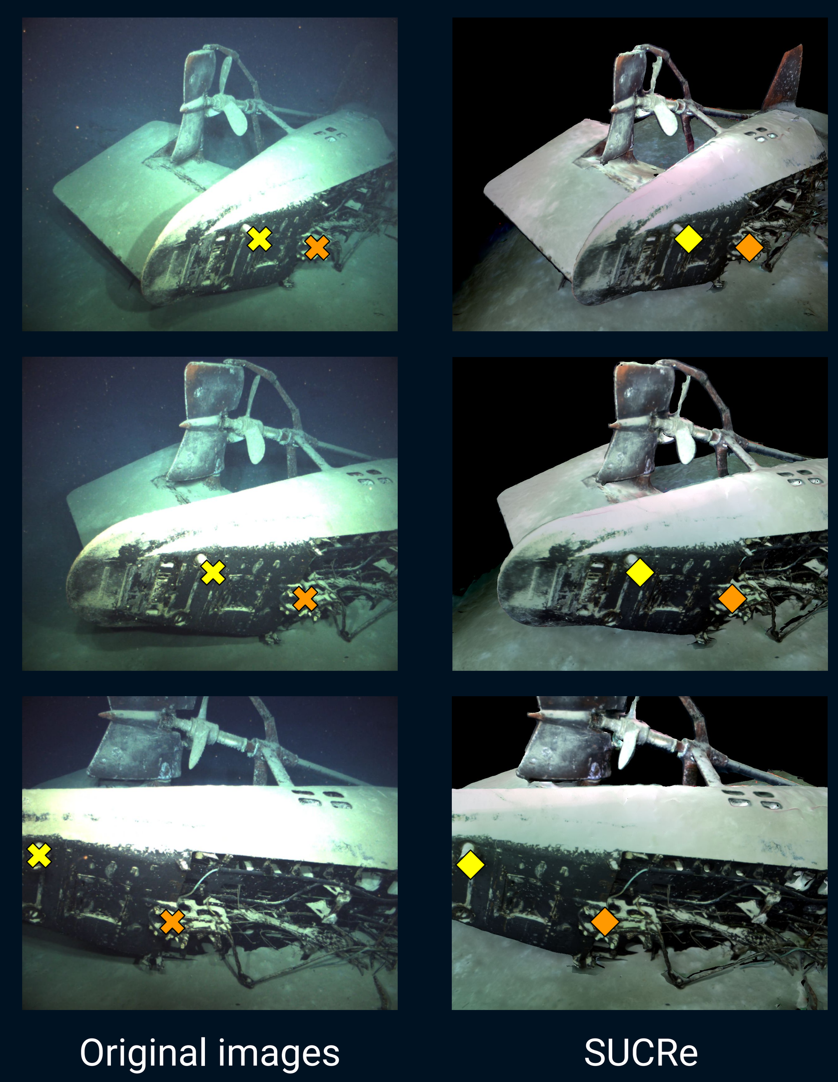
Both phenomena depend on the distance between the camera and the observed scene

Single-image restoration methods face limitations:
- More **unknowns** than observations
- Information is lost due to **quantization**

Method – Multi-view color restoration

We use SfM/MVS dense reconstruction results to constrain the estimation of absorption and backscatter parameters





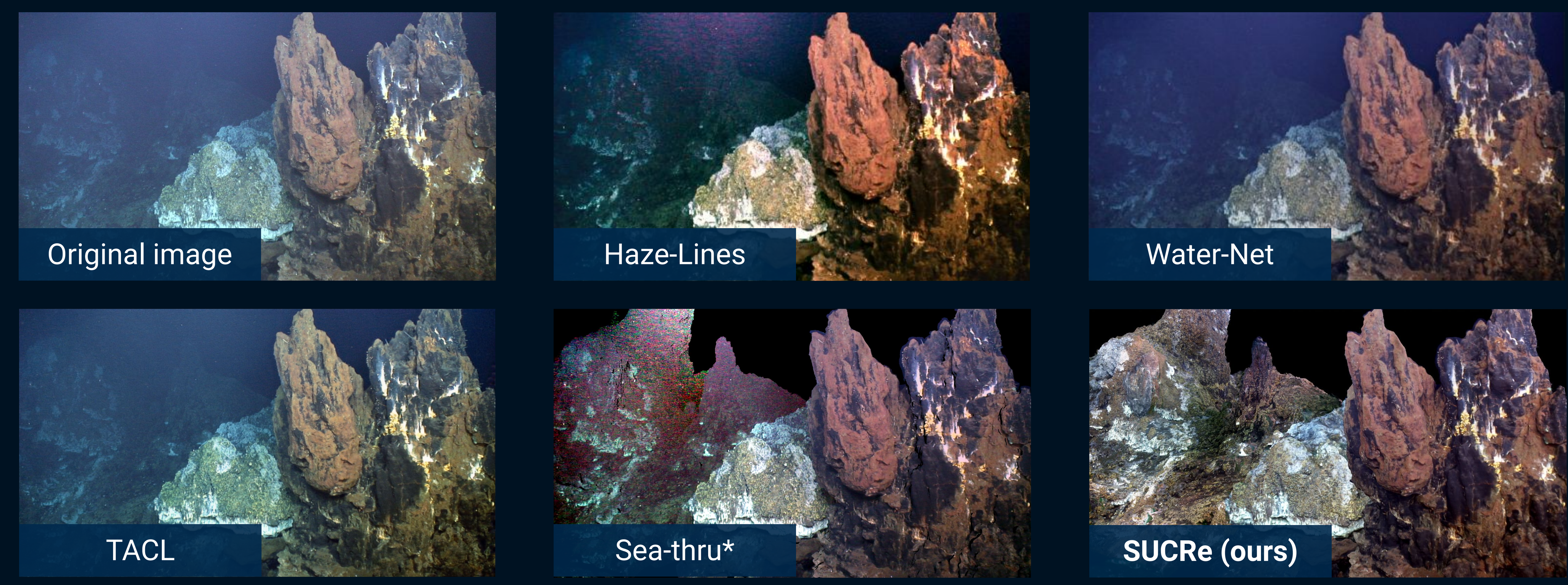
We track pixels in multiple images to retrieve their intensities at different distances:
- We can estimate **simultaneously** unattenuated pixel intensities along with absorption and backscatter parameters
- Multi-view pixels benefit from **virtually augmented dynamic range**

$$\underset{\boldsymbol{J},B,\beta,\gamma}{\arg\min} \sum_{i} \sum_{p} \| \boldsymbol{I}_{i,p} - \boldsymbol{J}_p e^{-\beta \boldsymbol{z}_{i,p}} - B(1 - e^{-\gamma \boldsymbol{z}_{i,p}}) \|^2$$

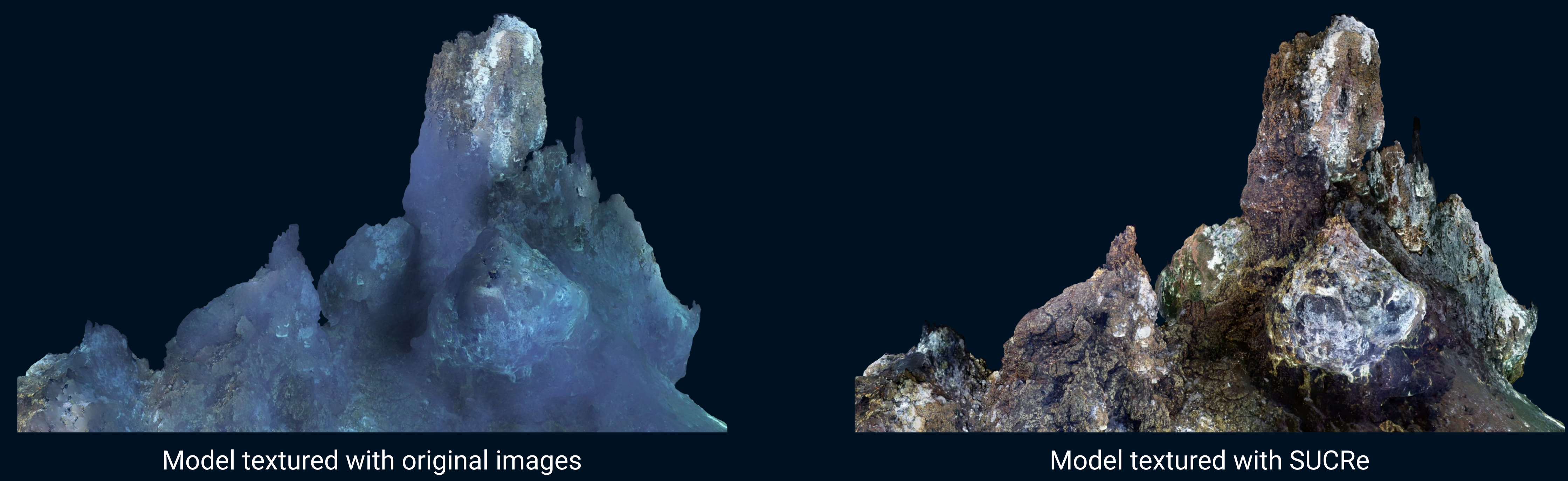
Acquired pixel intensity ($\boldsymbol{I}_{i,p}$); Absorption coefficient (β); Backscatter coefficient (γ); Unattenuated pixel intensity ($\boldsymbol{J}_p$); Veiling light (B); Pixel distance ($\boldsymbol{z}_{i,p}$); Image index (i); Pixel index (p)

From these pixel intensity/distance pairs, we express an underwater image formation model in a multi-view setting
We estimate parameters with a least squares – this formulation is close to **bundle adjustment** with fixed poses:
- Estimate the **3D points' colors** instead of their positions
- Estimate **absorption** and **backscatter** parameters instead of camera intrinsics

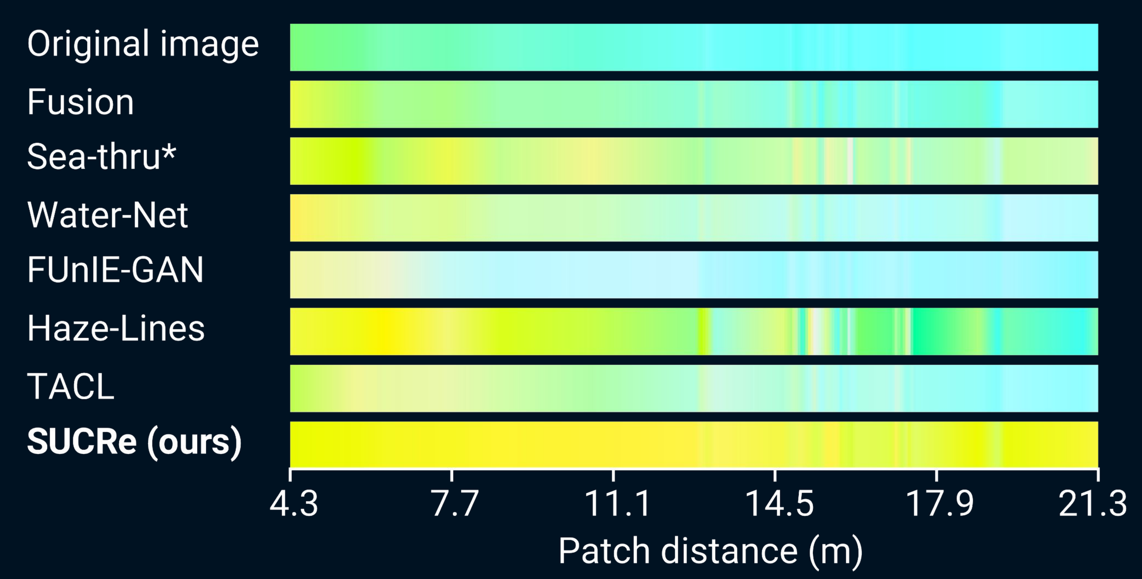
Results

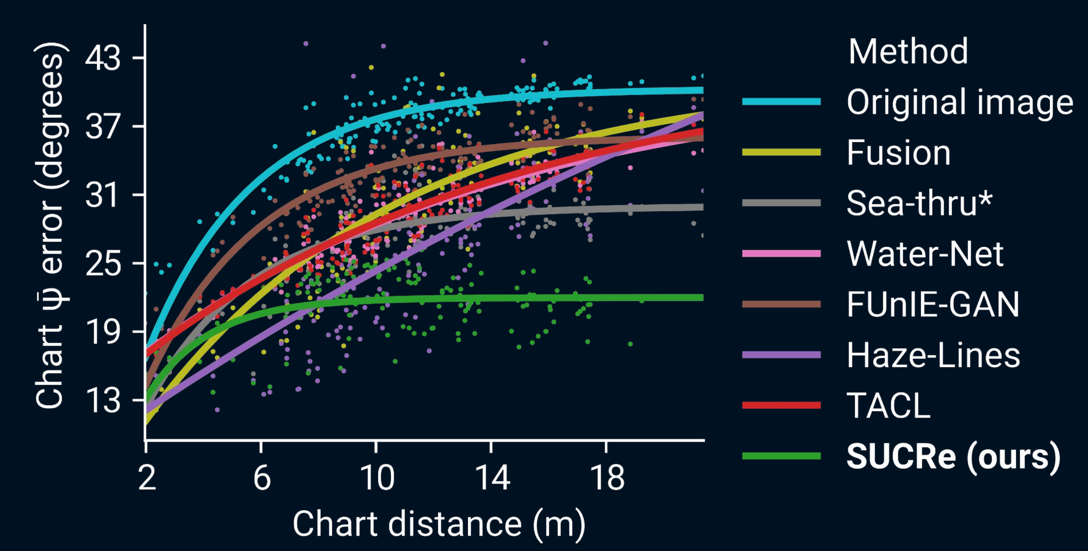


Our method allows for recovery of colors **even in very low contrast** image areas



Texturing 3D meshes acquired in real-world oceanographic campaigns with SUCRe





Method	Varos		*Sea-thru* D5			
	PSNR ↑	SSIM ↑	$\bar{\psi}$ ↓	$\bar{\psi}$ std ↓	ΔE_{00} ↓	ΔE_{00} std ↓
Original image	10.71	0.39	37.14	3.72	36.93	3.68
Fusion	10.25	0.35	29.85	6.38	30.60	6.34
*Sea-thru**	10.15	0.39	27.55	3.68	30.64	5.46
Water-Net	11.20	0.38	29.12	4.11	31.49	5.89
FUnIE-GAN	11.02	0.35	32.91	3.63	35.55	5.07
Haze-Lines	9.64	0.36	25.80	7.14	28.85	6.89
TACL	10.02	0.36	29.28	4.27	30.50	4.93
SUCRe (ours)	**12.13**	**0.42**	**21.45**	**2.63**	**22.56**	**2.84**

Quantitative evaluation on a real-world dataset containing color charts, and a synthetic dataset with reference images:
- Our approach shows consistent lower $\bar{\psi}$ error independently of the distance between the color chart and the camera